Lunar-Like Chronology for Vesta - Crater Retention Ages Matching Independent Ar-Ar HED Ages.

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Introduction: The first spacecraft dedicated to investigate a Main Belt asteroid, Dawn, entered orbit around (4) Vesta in July 2011. Dawn completed its mapping task at Vesta from different altitudes with a second high altitude mapping orbit in July 2012 and embarked to its next destination (1) Ceres [1] in September 2012. The Main Belt is believed to be the main impactor source in the inner solar system [2,3,4]. Among the inner Solar System planetary bodies the lunar cratering record has been investigated by many scientific groups for decades. Thus, it is one of the best known planetary surfaces in the Solar System. Several asteroids investigated by spacecraft such as (951) Gaspra, (243) Ida, (21) Lutetia and now (4) Vesta show cratering records very similar to the lunar cratering record. This suggests a common impactor source, which is the asteroid Main Belt and therefore, it also suggest a similar cratering chronology [5]. We update our earlier results of crater counting on Vesta [6,5] and find good agreement of the formation ages of major impact structures on Vesta with Ar-Ar reset ages of HED meteorites [7], which most likely originated from Vesta [8].

Crater Size-Frequency Distribution (CSFD): We derived the vestan CSFD from the lunar crater production function [2] by application of scaling laws [9]. In general our resulting production function agrees well with the measured crater distribution on Vesta. Between about 8 and 15 km crater size areas older ~2.2 Ga show a steep crater distribution inconsistent with the derived vestan crater production function. If the observed population of the Vesta collisional family (Vestoids; [10]) is scaled to crater sizes with about 500 m/s impact velocity the observed steep crater distribution between 8 and 15 km can be successfully corrected (Fig.1). The lower boundary of 8 km of the Vestoid contribution may be explained by initially high ejection velocities of small fragments and strong Yarkovsky drift of small family members [11]. The steep crater distribution on old areas cannot easily be explained by secondary impacts from the Rheasilvia formation, because the required impact velocity of the respective projectiles exceed the vestan escape velocity of 366 m/s. The Rheasilvia basin is believed to be the last major source of Vestoid replenishment [12,13]. Based on ejecta scaling [14] and hydrocode modeling [15] we find on the order of 2 to 5 times of the observed Vestoid population escaped Vesta due to the Rheasilvia formation which is in agreement with [12] and [13]. Probably a significant part of this material reimpacted Vesta in the following few hundred Ma, because of the high impact probability of barely escaped large fragments. Therefore, the steep Vestoid contaminated cratering record should also be observed inside the Rheasilvia basin in case all of the mass wasting processes were finished shortly after the impact event [16]. This is not the case. Thus, we conclude the basin interior was heavily resurfaced long after the basin formation by mostly mass wasting processes on the currently still ~7°- ~15° inclined slopes of the basin walls. Loosely packed surface material may become mobilized by relatively small intra basin impacts and thus easily reset the crater retention age. Vestoids have ceased to contribute significantly to the vestan cratering at least since ~2.2 Ga.

Crater Chronology: Similar to the CSFD we used the lunar chronology [2] and scaled it to the impact conditions on Vesta. Crater frequencies on ~3.8 Ga old areas are above the lunar equilibrium distribution but still show a steep roughly -3 cumulative production function at ~2 km crater size. This allows for deriving reliable surface ages on old areas and without significant contamination by Vestoids.

Results: We date the interior of the Rheasilvia basin with 2.2 (+/- 0.19) Ga. The formation age of this basin is inferred from topographic high points, where mass wasting is much less efficient. A small area on top of the central peak of Rheasilvia is dated with 3.59 (+0.079/-0.18) Ga. The Rheasilvia ejecta blanket at the Oppia crater ~40 km north of the basin rim is dated with 3.62 (+0.054/-0.087) Ga and 3.63 (+0.058/-0.096) Ga. Several resurfacing ages in the northern hemisphere also scatter between ~3.56 and 3.59 Ga, suggesting significant seismic activity (no significant ejecta blanketing) at around the same time we find for the formation of the Rheasilvia central peak and the proximal Rheasilvia ejecta blanket. We also find an older resurfacing age in the northern hemisphere of Vesta, which scatters in the different areas between ~3.74 and ~3.8 Ga. We link these ages to the formation of the smaller and older Veneneia basin, because a few areas with such ages, are specifically modified by tectonic effects during the Veneneia formation such as the Saturnalia Fossa formation (3.78 (+0.038/-0.051) Ga), which is characterized by a Veneneia connected system of troughs [17]. Close to the Octavia crater we measured the Veneneia ejecta blanket with 3.78 (+0.042/-0.059) Ga. This indicates both basin forming events had a significant resurfacing effect in the northern hemisphere of Vesta. Due to the lack of thick ejecta blanketing north of the vestan equator, the resurfacing is likely be the result of massive seismic activity as it is suggested by hydrocode modeling [18].

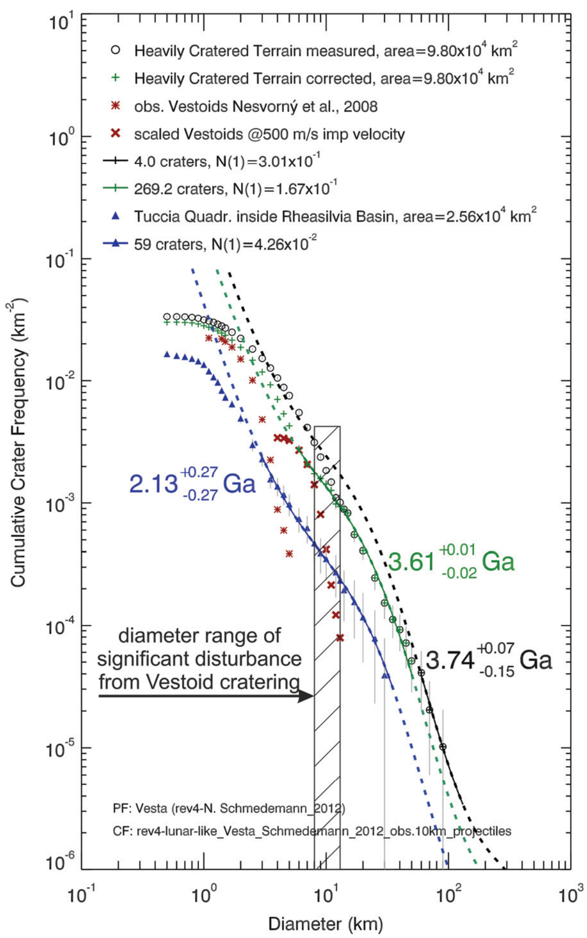

Fig.1: *Vestoid cratering disturbs the measured crater distribution on old areas (black circles: ~3.74 Ga + resurfacing at ~3.61 Ga → measurement should follow green isochron). It is not observed on areas as young as ~2.2 Ga (blue triangles) indicating a shrinking population and cratering effect. The measured steep distribution between 8 and ~15 km crater diameter can be corrected (green plus signs) with the observed Vestoid distribution (asterisks, arbitrary frequencies), if it is scaled to crater sizes assuming 500 m/s impact velocity (crosses). Corrected crater frequencies follow the same isochron like uncorrected larger crater frequencies.*

Crater Retention Ages Matching HED Ages: In order to compare our results of absolute crater retention ages from several areas on Vesta with Ar-Ar age probabilities, we derive an age probability plot where we sum up the age probabilities of all derived crater retention ages within each of the two clusters of crater retention ages. We define a younger cluster between 3.0 and 3.7 Ga and an older cluster between 3.7 and 3.9 Ga. In addition, we plot the global surface age of Vesta including all large impact structures for the two cases of including and excluding the tectonically resurfaced North Pole area. We find a crater retention age from the combined measurements of the younger age cluster of 3.58 (+0.07/-0.12) Ga. This age dates the formation of Rheasilvia and corresponds within the error bars with a peak in HED Ar-Ar age probabilities at ~3.55 Ga [7]. The older cluster in crater retention ages gives a combined result of 3.75 (+0.05/-0.21) Ga. This age likely dates the formation of the Veneneia basin. It also has a corresponding peak in HED age probabilities within the error bars at ~3.78 Ga [7]. Even the global age we derived from the largest impact structures on Vesta corresponds to peaks in HED ages either at 3.9 or at 4 Ga [7]. We tend to assume that 4 Ga is more likely for the global age, because probably not all large impact structures are identified yet.

Acknowledgement: This work has been supported by the German Space Agency (DLR) on behalf of the Federal Ministry of Economics and Technology, grants 50OW1101 (NS, TK), 50QM1001 (GM) and 50OW1102 (OR, HH).

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